it was not noticeable till 15^m after stars of the brightness of γ *Arietis* had shone out, and not quite so soon as the *Milky Way* at equal altitudes. Its whiteness more dusky than the latter. At an altitude of about 20° η and α *Piscium* (the latter just within the boundary) were somewhat dimmed by its intensity.

Upton Helions Rectory, Crediton,
1874, *March* 9.

Note on the Zodiacal Light. By E. B. Knobel, Esq.

I would beg to direct attention to the unusual brilliancy of the Zodiacal Light this winter.

It is stated in text-books that the Zodiacal Light is only visible in the evenings, in this country, in the spring months; and I have repeatedly observed it in March and April, but have never seen it more brilliant than in January and February of this year.

On two clear evenings in the first week in January, on January 17, at 6 45 P.M., and lastly on February 8, at 7 P.M., it appeared as an elongated luminous cone, the apex of which on January 17 extended nearly to the star γ *Arietis*, and on February 8 the apex just enclosed η *Piscium*.

It appeared nearly as bright as the *Milky Way*, and sufficiently bright to attract the attention of a casual observer.

I should mention that my situation is quite away from the town, and sufficiently high to be above the mists of the valley.

Stapenhill, Burton-on-Trent,
1874, *Feb.* 11.

On the Structure of the Solar Photosphere. By S. P. Langley, Esq.

(*Communicated by Mr. Lockyer.*)

During some years past the spectroscopic investigation of the solar surface has furnished new and valuable results so continuously, as to engross the attention of observers almost to the exclusion of older methods. I have been led, however, to think, that much of interest remains to be reached by direct telescopic scrutiny of the Sun, and that among the facts thus to be gathered are some concerning which the spectroscope cannot inform us, and some which will aid us to interpret its indications.

It will be remembered that an interesting controversy arose

out of the announcement of Mr. Nasmyth's "willow-leaf" structure; and that, after eliciting valuable communications from Messrs. Dawes, Lockyer, and others, it may be said to have closed with a paper by Mr. Huggins, which appeared in the *Monthly Notices* for May 1866. Since this, with the exception of some observations of Padre Secchi, little of essential importance has been added to our knowledge of the intimate structure of the photosphere. As the nomenclature of this subject is in complete confusion, it is necessary to call attention to the fact, that I here mean by "rice-grain" exactly what Mr. Huggins denotes by "granule,' (I quote him here from memory), and that I reserve the latter word for a restricted and distinct use. The word "rice-grain" is descriptive of the appearance of certain components of solar clouds, but has no special value as a simile, save for what is seen with moderate apertures;* such as were employed by Messrs. Stone and Dunkin, who first used the word. By "rice-grains" are here meant certain universal constituents of solar clouds, visible only in fine definition; presenting a precise shape as compared with those larger but vaguer cloud-forms or mottlings which are visible on the photosphere with lower powers; of an irregular outline, frequently rudely oval; whose average dimension of from 1″ to 2″ is yet sometimes fallen short of, sometimes exceeded; which to ordinarily careful observation seem in close juxtaposition, and separated by narrow intervals which are not uniformly dark; the rice-grains themselves being of vivid, but unequal brilliancy, and in the language of Sir John Herschel, "the immediate sources of the solar light and heat."

With an object-glass of thirteen inches, possessing great perfection of figure, and which has been employed with undiminished aperture by aid of the polarising eye-piece, I was led to notice that the rice-grains were by no means in such close juxtaposition as at first appears; the large aperture, by reducing irradiation, helping to make it more easily visible, that these bodies, though the chief sources of the solar light, occupied but the smaller portion of the solar surface.

In measuring them by the filar micrometer, and in reckoning their number (by the aid of a reticule kindly ruled for me in minute squares on thin glass for this purpose, by Mr. Rogers), I was led to notice that my estimates of both size and numbers varied with the magnifying powers employed, in a way which seemed unaccountable on the supposition that rice-grains were individual things of approximately uniform size. By taking advantage of the brief and rare intervals of definition, which admit the use of the high powers of such a telescope, I found the cause in the resolution of the rice-grains into an order of minuter components, hitherto scarcely observed. These components I here

* Mr. Stone observed the "rice-grains" with the Great Equatoreal at the Royal Observatory, the clear aperture of which is 12·8 inches.—[Editor.]

term *granules* (a word used by others as a synonym for "rice-grains," and to which a distinct and restricted significance is, it should be noticed, here attached). They are very minute bodies present over the whole solar surface, faintly discernible in the faculæ, and in the penumbræ of the spots are extended into long filaments, whose aggregation forms the "thatch-straws" of Mr. Dawes, as the aggregation of granules forms the rice-grain. The latter term should be employed hereafter, I think only so far as it may be necessary to recognise a tendency of these granules to unite in clusters of approximately uniform size. The granules are occasionally seen singly, more frequently united in clusters of from two or three to ten or more ("rice-grains"), and by their degree of juxtaposition, and perhaps by their partial superposition, form the inequalities of brilliancy of the rice-grain noted by Mr. Huggins, and account for the irregular outline of the latter, which he has already remarked upon. With the largest apertures and powers not only then do these brilliant bodies appear smaller, but from their apparent area is to be taken the minute dark spaces which it now appears intervene between their own component parts.

It hence became a matter of interest to determine approximately the average number of granules to a given area, and their size, since it was increasingly evident that the part of the solar surface which is principally concerned in sending us light is much smaller than has been supposed.

The general background on which the granules appear is grey by comparison, not uniform in shade but faintly mottled, and its light is very probably also due to the presence of granules, partly dissipated or concealed.

We are not now concerned with this further than to remark that, if this be so, it does not affect the following estimates of the brilliant area, which rest upon the fact that though granules and mottled interspaces here and there merge into one another, there is yet between these ultimate constituents of solar clouds and their background, a distinction so great that we are warranted (for the purpose at least of a first classification), in treating the solar surface as though it were composed of uniformly bright granules, divided by uniformly grey intervals in which the light is certainly so inconsiderable that the granules appear brilliantly irradiant.

In our measurements, let us first remark, that owing to the vivid irradiation of these bodies, a conclusion as to their real size from their apparent angular dimension would be nearly as unwarrantable as a similar estimate would be in the case of a bright fixed star. To evade this difficulty altogether seems impossible, yet I believe the course adopted fixes an upper limit for their apparent size. It has been remarked that the granules are continuous with certain long filaments in the penumbræ; and these filaments, though often much contorted, are in the normal type of penumbra radially disposed, and closer as they converge

toward the centre. By repeated measurements with the filar micrometer, and by other means, it was found that the distance of these filaments varied widely, but that where they lay closest their centres were certainly less than 0″·6 apart. As it may be safely assumed that two bright lines separated by an interval of less than 0″·3 would appear as one in the instrument and with the power employed, it appears that the interval between the filaments observed at least equals their width, which cannot in this case be more than three-tenths of a second of arc, and which, not improbably is much less. But filament and granule are apparently different aspects of the same thing, the granules being the upper end of filaments disposed, in this view (which is partly Mr. Dawes's) in a general sense vertically over the Sun.

The granule being certainly not materially larger than the filament at its extremity, we cannot consider it as over 0″·3 or 0″·4 in diameter. I feel increased confidence in the result of these difficult measurements, from the fact that Secchi, who is the only observer who appears to have seen them, speaks of minute objects he terms *grains*, as covering the whole solar surface, and whose diameter he estimates at from a third to a quarter of a second of arc. These, are doubtless, identical with the objects here termed granules, though they are treated by Secchi as identical with the "rice-grains" of Stone, and the "willow-leaves" of Nasmyth, with neither of which will their size permit us to confound them. Having the size of the granule at its upper limit, their number is obtained by the aid of the Rogers-reticule and by actual count. This is a work of extreme difficulty. I find that if the granules were uniformly distributed we should have rather less than one to each second of arc; but I should here state, that I have reason to believe it probable that neither granules or filaments are "entities" in any other sense than "rice-grains" are. Filaments of immeasurable fineness are at times seen projected on the umbræ, looking, collectively, like carded wool, which are intimately connected with those measured; and though it would not be right to ignore the fact of a tendency to certain more or less definite groupings, which have a real existence, and to which we give here such names as "granules" or "rice-grains," according to their order of magnitude, we must not be misled by our own nomenclature to claim for any of these an objective reality in the sense at one time attributed to the "willow-leaves." There is no improbability then that the division will be hereafter carried further; but it is essential to note that as the increase of the number will imply a proportionate diminution of size, we have, if our present estimates of the relation between size and number be correct, already data which will enable us to fix an upper limit of the ratio of the proper illuminating surface to that of the whole photosphere, which cannot be disturbed by subsequent minuter discrimination. I do not feel that the data given are exempt from considerable possible error, owing to the great rarity of the occasions when they can be gathered or verified; but after making

every reasonable allowance for this, we cannot reach the result of our computation without surprise, for it leads inevitably to the conclusion that the Sun's light comes chiefly from an inconsiderable portion of its surface, and I cannot myself estimate this portion at more than one-fifth of the whole.

I have been led to think that the study of the forms assumed by the filaments will give information of interest as to the character and direction of the currents in the photosphere, whose existence Mr. Lockyer and others have already demonstrated by the spectroscope. These may be studied to most advantage in the penumbræ. The darker shade, around the outer penumbral edge, is, I observe, ordinarily only that of the grey matter everywhere on the surface, serving as a background for the granules; and the evidence from a prolonged study of the minute structure here, seems to show that this edge is formed by rupture, by a stress that is, acting laterally and downwards, and not by a deposition of the constituents of ascending currents.

These filaments are not only more brilliant at the umbral edge (as if their extremities were curved upward, and less obscured, where partly elevated above a darker supervening medium), but this tendency may be traced in good definition, all over the penumbra, in which they have a certain tendency to unite in narrow sheets or plates, which, superposed, form the fascicles called "thatch-straws" by Mr. Dawes. In the umbra, the detached bright points, observed by Mr. Lockyer and others, are found to be tips of filaments thus raised, the part of the filament extending under the umbral shade being frequently, by proper precaution, dimly, but unequivocally traceable through it, and found continuous with a portion of the penumbra. By the aid of the polarizing eye-piece, and by excluding as far as possible extraneous light, the whole umbra is seen at times to be nearly or wholly made up of sunken banks of the filaments; the umbral structure being quite complex, and presenting the appearance of a submerged penumbra, and the nuclei of Mr. Dawes, being only deeper portions of its shade.

By means, for the detailed description of which there is not here space, I have isolated one of these nuclei from the surrounding umbra. Mr. Dawes terms the nucleus *intensely black* (the italics are his), but thus viewed it is not "black," not even dark, except in a relative sense, but brilliant with a violet-purple light. I regret that I have been unable to obtain, as yet, photometric measurements of the luminosity, but when seen alone it might fairly be described as dazzlingly vivid, the appearance being like that of a violet star, and very striking. The observation is one which may have been already made; yet I have not seen any determination of the light of the nucleus as distinguished from the umbra, and its interest in connection with the disputed question of the transparency of the Sun's interior induces me to give it a place here.

I have never been able to satisfy myself by direct telescopic

scrutiny, whether these "banks" in the umbra have an invariable direction of motion, whether of ascent or descent. Nearly all my observations have tended to confirm me in the impression that they moved as if under the direction of a downward current; yet in one instance I have seen the contrary, and in this case the evidence of ascent seemed unequivocal. Mr. Lockyer (*Monthly Notices*, June 1865) has noticed in one instance the fact of the existence of superposed currents moving in different directions. I think this nearly isolated observation may be greatly extended; and I can, from what I have repeatedly seen, entertain scarcely more doubt of the frequent superposition of approximately horizontal currents of the different strata of solar clouds than of our own.

What may be almost called the typical form of solar currents, the cyclonic, has been left unmentioned. Of the various kinds of this as traceable by the disposition of the flexible filaments, I have made a very considerable number of sketches which were in every case finished at the telescope, and though inartistically, yet, I believe, not unfaithfully represent the forms seen there. Any complete discussion of these would be impossible here, but it may be stated generally—

That the normal type of cyclone contemplated by M. Faye as embracing the whole spot in a common movement of rotation is extremely rare.

That the evidence of cyclonic action is nevertheless everywhere present in the spots. The radius of curvature of the filaments diminishes rapidly to the centre of the whirls, which are very numerous in large spots; often completely independent when in apparent juxtaposition, or even apparently in part superposed, and sometimes rotating in different directions.

That the axes of these whirls are not always vertical, but are occasionally met with inclined at all angles.

That the filaments in incipient, small, or growing spots are less frequently seen moulded by any uniform cyclonic action than in forms whose disposition is nearly that seen in processes of crystallisation, or gemmation.

Padre Secchi almost alone has given some illustrations of these "crystalline" forms, and it is to be wished he had given more. I have myself seen some so unlike anything we should be prepared to expect from the ordinary published illustrations, that I should be glad to have the independent evidence of so eminent an observer to refer to in making them public. I can only say here, and in the absence of special illustrations, that this crystalline appearance is very remarkable not only in itself, but from its contrast with the flexible forms the filaments ordinarily assume, and that the most peculiar types are confined to large spots, such as at the present time rarely present themselves.

Both in their points of resemblance to, and distinction from ours, however, the solar clouds are of interest to the terrestrial

meteorologist; but many more observers are wanted in this direction than we have at present, and it would be especially desirable if photography could do for the details of spots what it has already done for the laws of their movement. Our own atmosphere is the great obstacle, and a more serious one in observations by day than by night, as weeks may pass without bringing an hour of definition suitable for the best use of the very large apertures indispensable for some of the observations which have been detailed, and their demand upon the time of the professional astronomer having other duties is frequently too great to be met. I should hardly have felt justified in commencing observations of this kind had I known the assiduous attention they require in awaiting what are in our climate the rare moments when they can best be made. I shall feel less regret for the disproportionate time thus spent, if the present communication should be at all instrumental in directing the attention of those private observers now possessing powerful instruments of a class comparable with that used to a most interesting field of research, as yet scarcely occupied, and in which their labours may be instrumental in laying the foundations of a future science of solar meteorology.

Allegheny Observatory,
Allegheny, Pennsylvania, 1874, January 30.

On the Approximate Calculation of the Times of Solar Eclipses.

By J. N. Lewis, Esq.

(*Extract from a Letter to Mr. J. W. L. Glaisher.*)

In the *Monthly Notices*, Vol. xxxii. p. 332, is an article by the Rev. S. J. Johnson, "On Future Solar Eclipses." In calculating these he makes use, for brevity, of the Tables contained in the eighth edition of the *Encyclopædia Britannica*, and he says he finds only one instance in which they are more than nine minutes out in the time of greatest obscuration. This recalls to mind that I prepared, a few years ago, a set of Tables of still greater brevity than those in the *Britannica*, and, according to the testimony of Mr. Johnson, more accurate also. As to this latter point, some results are given in the following Table. The Table of Epochs was prepared from the elements of the Moon's orbit given by Hansen (*Tables de la Lune*) and of the Sun's orbit by Le Verrier (*Annales de l'Observatoire de Paris*, tome iv.) taking into account the secular equations; and the equations to reduce the mean to the true syzygy were computed from the formula in Burckhardt's *Tables de la Lune* (Paris, 1812) p. 87, two small Tables being added for the purpose of taking into account the "Reduction," and the change in the velocity of the Moon's motion between the mean and the true syzygy; also for the Moon's latitude,